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CALIBRATION OF SEISMIC WAVE PROPAGATION IN KUWAIT

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ABSTRACT

The Kuwait Institute of Scientific Research (KISR), the USGS and LLNL are collaborating to calibrate seismic wave propagation in Kuwait and surrounding regions of the northwest Arabian Gulf using data from the Kuwait National Seismic Network (KNSN). Our goals are to develop local and regional propagation models for locating and characterizing seismic events in Kuwait and portions of the Zagros mountains close to Kuwait.

The KNSN consists of 7 short-period stations and one broadband (STS-2) station. Constraints on the local velocity structure may be derived from joint inversions for hypocenters of local events and the local velocity model, receiver functions from three-component observations of teleseisms, and surface wave phase velocity estimated from differential dispersion measurements made across the network aperture.

Data are being collected to calibrate travel-time curves for the principal regional phases for events in the Zagros mountains. The available event observations span the distance range from approximately 2.5 degrees to almost 9 degrees. Additional constraints on structure across the deep sediments of the Arabian Gulf will be obtained from long-period waveform modeling.

Key Words: Seismic Regionalization, Calibration, Broadband Seismology.

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OBJECTIVE

Calibration objectives for seismic hazard assessment and CTBT monitoring often coincide, especially for event location and the estimation of magnitudes and mechanisms. From the perspective of hazard assessment, the following issues and tasks have high priority:

Assessment of Seismic Hazard from In-Country Earthquakes

- Determine the detection performance of the KNSN.
- Develop a local velocity model with KNSN earthquake observations.
- Construct a seismicity map for the country and territories immediately adjacent.
- Characterize seismic sources within and adjacent to Kuwait.
- Estimate attenuation rates of seismic waves in Kuwait.

Assessment of Seiusmic hazard from Earthquakes in the Zagros Mountains

- Calibrate regional travel times and attenuation.
- Characterize seismic events (moments and mechanisms) in the near Zagros Mountains.
- Estimate the strength of ground motion anticipated from events in the near Zagros at industrial and population centers of Kuwait.

These objectives overlap or support CTBT calibration goals as well. The larger in-country earthquakes, if well-located and well-characterized, can serve as calibration events for stations of the IMS. Although Kuwait is not very active seismically, it has had several events with magnitudes greater than 4.0 in recent years. Travel-time and phase amplitude calibrations for events occuring in Kuwait, and characterization of representative mechanisms, will permit these events to be located and screened with greater reliability. The seismicity of the Zagros mountains is a significant challenge for the IMS. The Zagros are among the most active areas of the Middle East; at least 17 earthquakes with magnitudes greater than 7 have occurred there this century. Figure 1 shows the distribution in a large part of the Middle East of events of the last 23 years with reported Harvard CMT mechanisms (Harvard Centroid Moment Tensor web page). A large fraction of these events, and a large fraction of events that will have to be located and screened by the IMS, are located in the Zagros mountains. The principal CTBT objective of this project is to provide better location, magnitude and mechanism constraints on calibration events in the Zagros region.

RESEARCH ACCOMPLISHED

The network and local hazard assessment

During April, 1999, a team of five seismologists and geophysicists from the USGS and LLNL visited colleagues at the Kuwait Institute of Scientific Research (KISR) to develop research collaborations for implementing objectives of the Kuwait National Seismic Network. The KNSN is a high quality digital network (Figure 2) consisting of seven short period stations (3 component Ranger SS-1 instruments) and one broadband station (with an STS-2 seismometer). The data are digitized by 24-bit Reftek 72A07 DAS's and telemetered digitally to KISR in Kuwait City. The network is synchronized with a GPS receiver at KISR and a heartbeat signal broadcast from the center to the field stations.

Four - six months of continuous data were selected for a detection study. These data will be processed with STA/LTA and matched filter detectors, and the detections screened by an analyst to develop a catalog of events against which the automated detection system at KISR can be evaluated and tuned. This task is expected to improve automated detection of local seismic events by the KNSN, and to assist in classifying local, regional and teleseismic detections.

During the KISR visit, we relocated 6 events (Figure 2) with the default model supplied by the system vendor to check the location performance of the current automated system (which uses just P waves). The relocations were performed with analyst picks for both P and S waves. Events with locations inside the network did not move too much upon relocation, but two events on the margins of the network did relocate far from the automatic locations.

In part, this behaviour suggests that a better velocity model is required. Accordingly, plans have been initiated to develop a better 1-D velocity model by:

- performing joint relocation of local events and velocity model estimation,
- searching for mining explosions as calibration events in the continuous data,
- constraining upper mantle velocities with two-station Pn and Sn differential travel-times,
- constraining crustal thickness / average velocity with receiver functions,
- constraining crustal shear velocities with two-station differential surface wave dispersion measurements
- full-wave synthetic modelling to constrain calibration event depths and mechanisms

An example of the use of full-wave synthetic modelling to constrain depth is shown in Figures 3 and 4. The modeling was performed for the southernmost event in Figure 2, a magnitude 4.2 earthquake (relocated) near the Al Minagish oil field. The waveforms were recorded at the nearby broadband station, and modeled with reflectivity synthetics in the 10-20 second period band using an average Arabian platform model with sediment thickness somewhat increased. Figure 3 shows the waveform fit for an assumed event depth of 7 km. Figure 4 shows the misfit error as a function of depth; the best-fitting mechanism is indicated for each depth. The depth is very sharply constrained by the local recordings, suggesting that when a good model is obtained, high-quality ground truth depths will be developed. This event and one other in 1994 are large enough to serve as calibration events for stations of the IMS.

We also calibrated the broadband station coda envelopes for magnitude estimation (Mayeda et al., 1999). Better estimates of magnitude will improve the estimation of b-values in seismic hazard assessment and detection thresholds for IMS stations.

Zagros Seismicity

Earthquakes in the Zagros mountains pose a potential hazard for the population and infrastructure of Kuwait. Events with magnitudes greater than 5.5 are common within 2-3 degrees of Kuwait City. The objective of hazard research in this context is to determine the likelihood of an event of magnitude greater than 7 in a position to produce strong ground motion in Kuwait in the forseeable future. Moment histograms constructed from ISC and NEIC data can be used to estimate recurrence intervals, but the data show a reporting threshold around 4.7 for the region. The KNSN should provide moment histograms and b-value estimates at lower magnitudes due to its proximity to the Zagros.

Once travel-time models are calibrated, the KNSN should provide good constraints on event locations in the Zagros, and help to improve estimates of the distribution of seismicity. Both P and S phases are well recorded at the broadband station from local distances to almost 9 degrees, as shown in the 16-event waveform sample of Figure 5.

For calibrating propagation from the Zagros to Kuwait and characterizing Zagros seismicity, we plan to:

- estimate recurrence intervals from KNSN detections using coda magnitudes
- calibrate travel time models with observations of ground truth (GT5 - GT20) Zagros earthquakes
- calculate mechanisms for large and medium events by reflectivity modeling
- estimate path models and attenuation rates from larger events with independently-constrained source parameters using reflectivity modeling and coda source spectrum estimates

References

Harvard Centroid Moment Tensor Web Page, www.seismology.harvard.edu.

Mayeda, K., R. Hofstetterr, A. Rodgers, and W. Walter (1999), Applying coda envelope measurements to local and regional waveforms for stable estimates of magnitude, source spectra and energy. proceedings of the 21st Seismic Research Symposium: Technologies for Monitoring the Comprehensive Nuclear-Test-Ban Treaty.

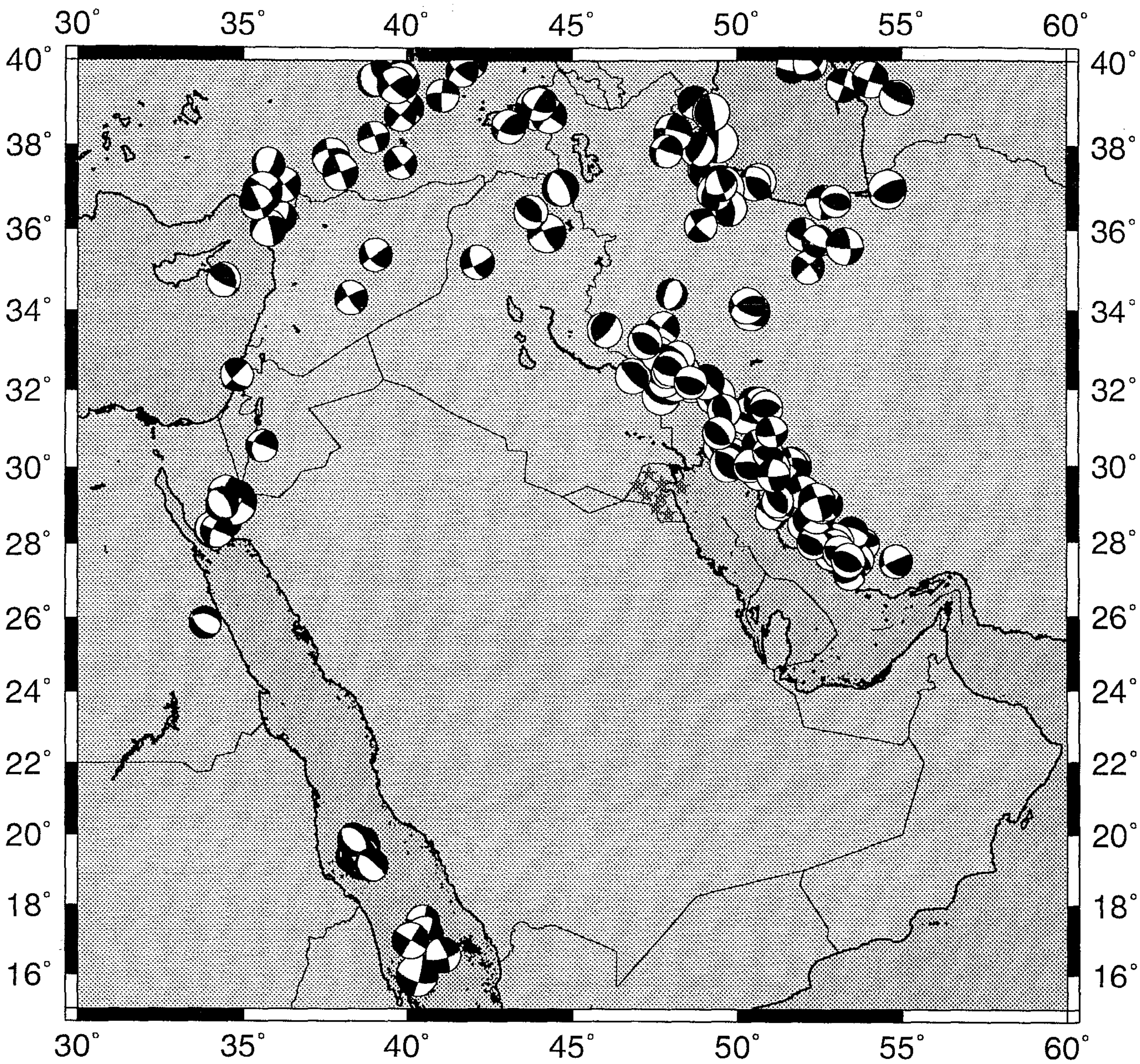

Figure 1 Focal Mechanisms for 23 years of Harvard CMT events from 1976 to 1999. Stations of the Kuwait National Seismic Network are shown as stars. The KNSN is ideally placed to study events in the Zagros mountains.

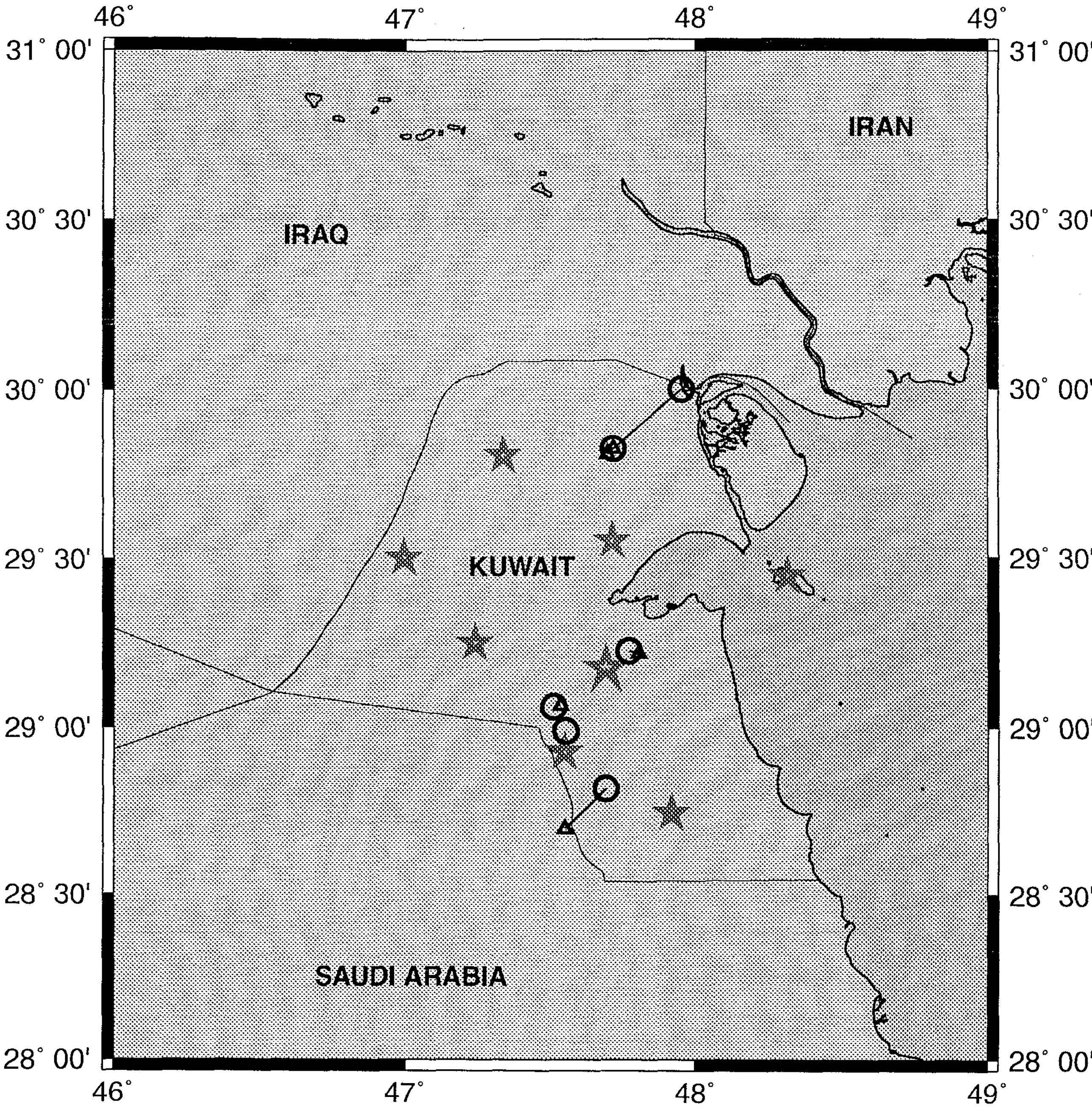

Figure 2 Kuwait is well-covered by the eight stations of the Kuwait National Seismic Network (stars). One of the stations (largest star) has an STS-2 instrument in a cylindrical vault 4 meters deep with three baffles insulating the instrument against wind noise and temperature variations. We have relocated six local events to test a default velocity model. Locations for five of the events made with automatic P picks are shown as small triangles. The corresponding locations with analyst picks using both P and S waves are shown as circles. Large mislocation vectors for two events at the margins of the network suggest the need to calibrate the local velocity model.

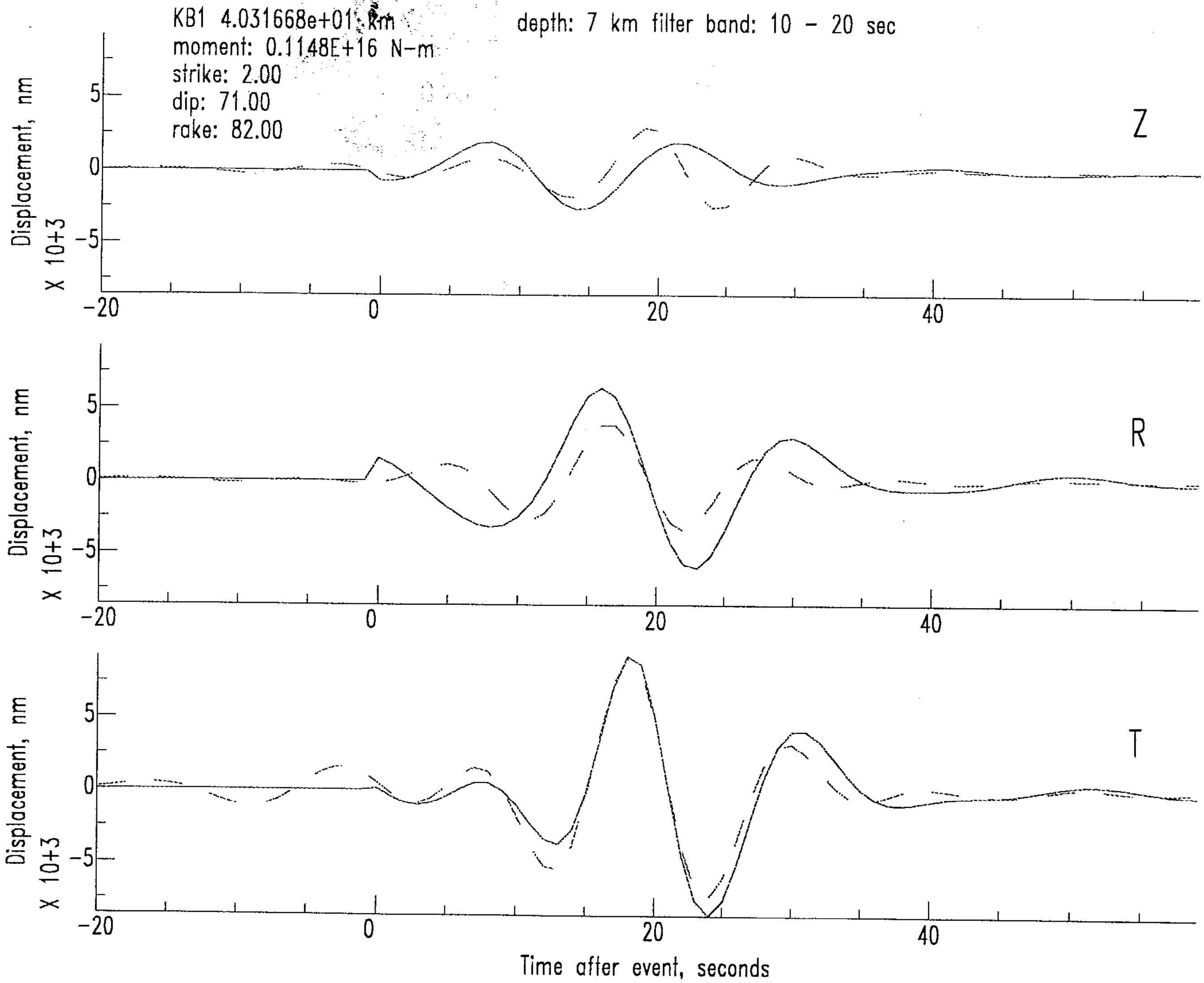

Figure 3 Comparison of broadband (10-20 sec period) reflectivity modeling waveforms with data recorded for the December 30, 1997 magnitude 4.2 event in southern Kuwait by the broadband station KB1 shows a reasonable modeling result. The data are represented by the dashed line and the model waveform by the solid line.

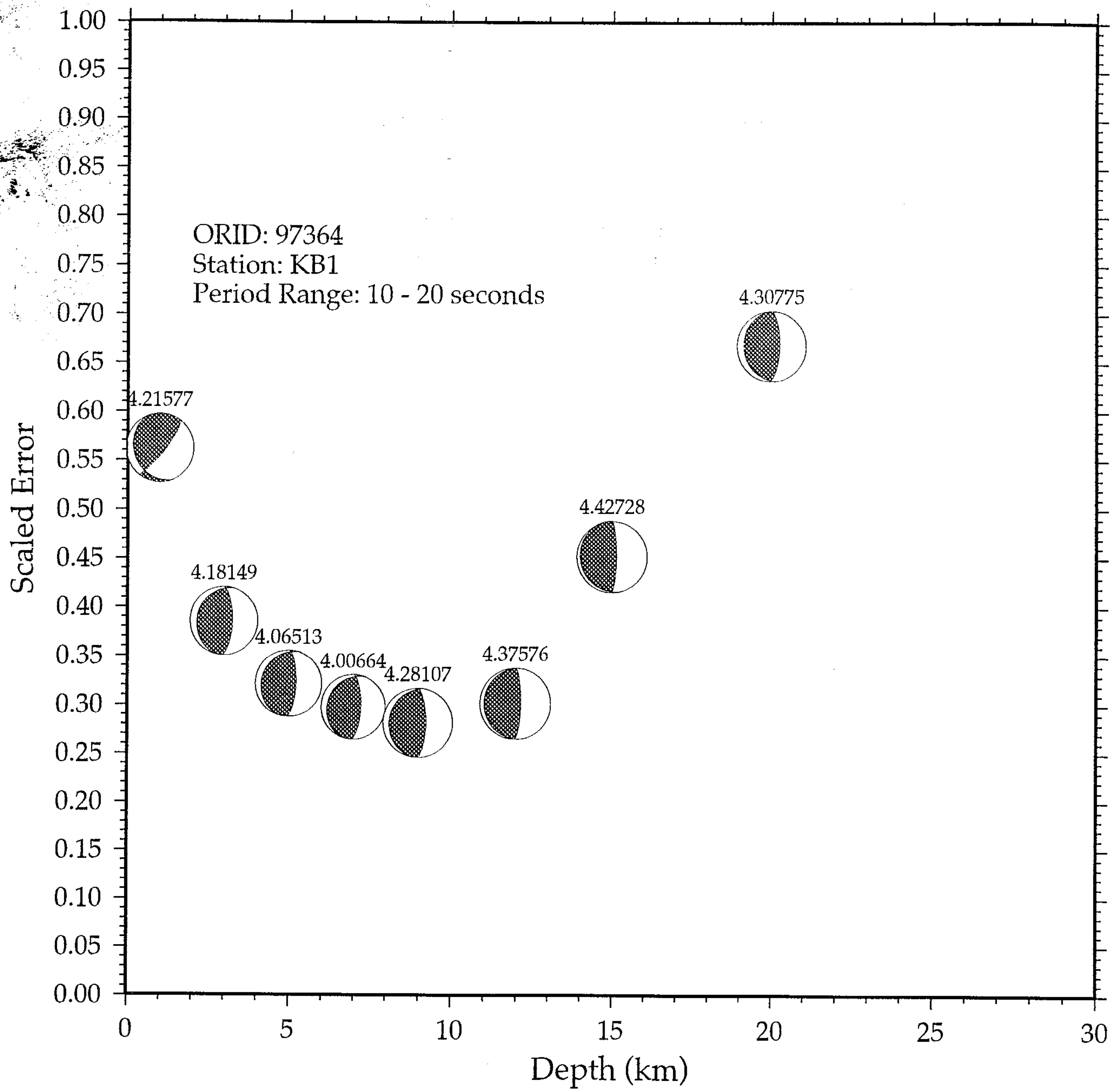

Figure 4 Waveform fitting error as a function of depth and me chanism for the December 30, 1997 earthquake in southern Kuwait shows the value of broadband data for constraining the depth and mechanism of local events in Kuwait.

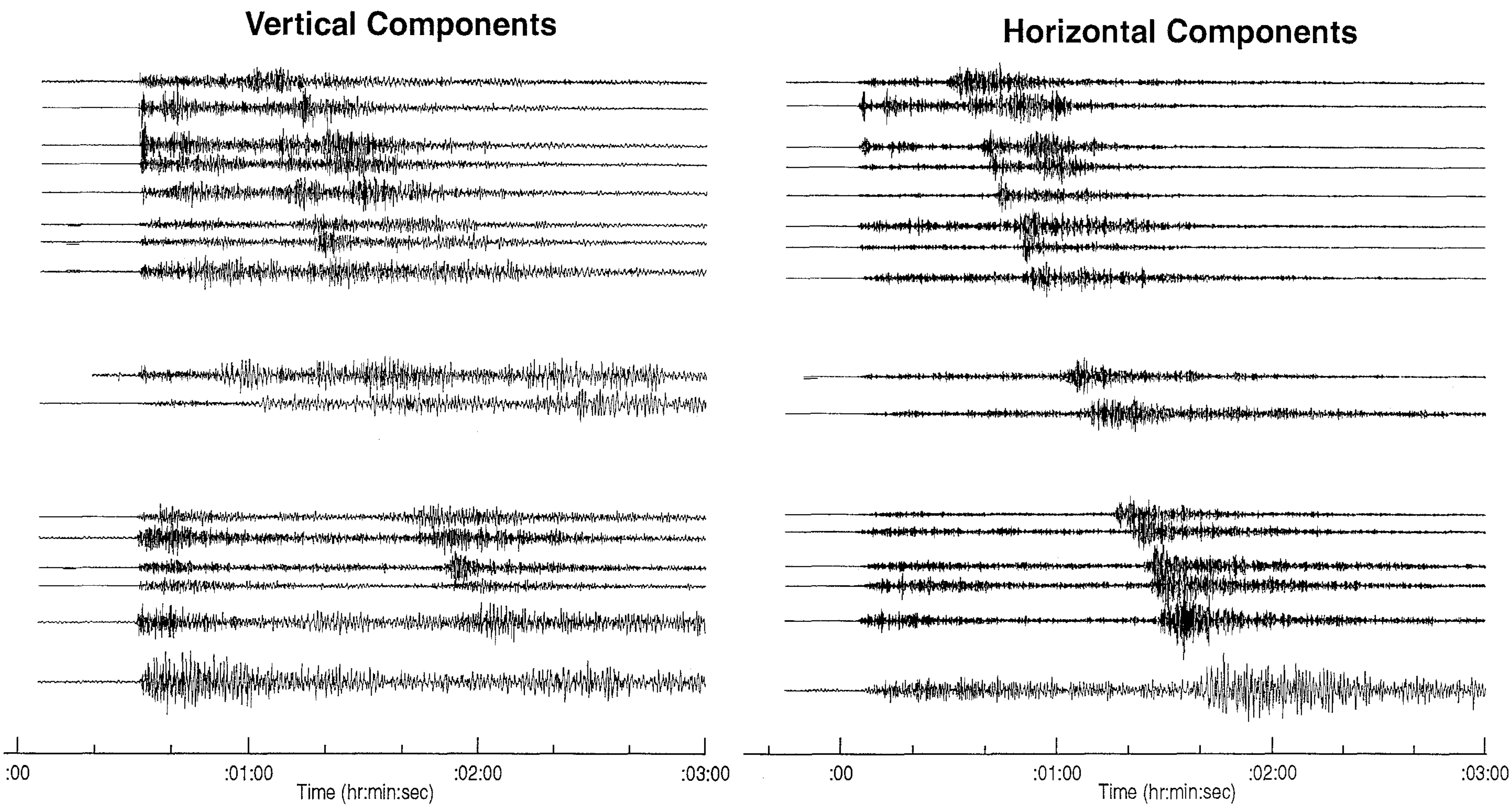

Figure 5 Waveforms of Zagros earthquakes recorded on the broadband instrument (KB1) demonstrate that P and S phases are well recorded. Sn appears to be particularly well-observed in this area. With sufficient ground truth information, well-calibrated P and S travel-time models should be obtained. The event records are plotted vertically from top to bottom with spacing proportional to increasing S-P time (not distance).